

PORTLAND HARBOR RI/FS

**APPENDIX E**

**EVALUATION OF POTENTIAL WATER QUALITY  
IMPACTS FROM THE TERMINAL 4 CONFINED DISPOSAL  
FACILITY  
FEASIBILITY STUDY**

June 2016

*This page left blank intentionally.*

## TABLE OF CONTENTS

LIST OF TABLES .....	E-i
LIST OF FIGURES .....	E-II
E1. INTRODUCTION .....	E-1
E1.1 Terminal 4 CDF design.....	E-1
E1.1.1 Terminal 4 CDF Components .....	E-3
E1.1.2 Terminal 4 CDF Elevation Control .....	E-4
E1.1.3 Terminal 4 CDF Capacity .....	E-4
E2. SHORT-TERM WATER QUALITY EVALUATION.....	E-3
E2.1 Berm Construction Water Quality.....	E-3
E2.1.1 Effluent Discharge during Hydraulic filling .....	E-5
E3. LONG-TERM WATER QUALITY EVALUATION .....	E-5
E3.1 Long-Term Water Quality Criteria.....	E-5
E3.1.1 Sequential Batch Leachate Tests.....	E-7
E3.2 Groundwater Transport Modeling.....	E-6
E3.2.1 Model Structure .....	E-9
E3.2.2 Boundary Conditions .....	E-9
E3.2.3 Groundwater Model Input Parameters.....	E-10
E3.2.4 Hydrogeologist Parameters .....	E-10
E3.2.5 Initial Source Concentrations.....	E-11
E3.2.6 Partitioning Coefficients .....	E-11
E3.2.7 Biodegradation Rates .....	E-12
E3.2.8 Long-Term Groundwater Results .....	E-12
E3.2.8.1 Groundwater Flow Characteristics .....	E-12
E3.2.8.2 Long-Term Groundwater Quality Predictions.....	E-12
E4. REFERENCES .....	E-13

## **LIST OF TABLES**

Table E-1	Bulk Sediment and Leachate Quality
Table E-2	Physical and Hydraulic Properties of CDF Materials for the Terminal 4 CDF Model
Table E-3	Geochemical Properties of Chemicals of Concern for the Terminal 4 CDF Model

## **LIST OF FIGURES**

Figure E-1	Terminal 4 CDF Plan View and Sections
Figure E-2	T4 CDF Model Structure
Figure E-3	T4 CDF Groundwater Flow Characteristics
Figure E-4(a-d)	T4 CDF Modeled Concentrations
Figure E-5	T4 CDF Contaminant Distributions at 475 Years

## E1. INTRODUCTION

---

Design analysis for the Terminal 4 confined disposal facility (CDF) is presented in the Terminal 4 Confined Disposal Facility Design Analysis Report (Anchor QEA 2011). The evaluations included estimates of potential short- and long-term water quality impacts to water quality using data available for the FS. Existing information from this analysis was used in the FS, and the information pertinent to an FS-level of evaluation from the Design Analysis Report is summarized in this appendix. Section 2 includes a summary of the short-term water quality evaluation, which addresses potential impacts to water quality from the construction and placement of sediment in the CDF. Section 3 includes a summary of the long-term water quality evaluation, which addresses potential impacts to water quality following the placement of contaminated sediment in the CDF and closure of the facility.

### E1.1 TERMINAL 4 CDF DESIGN

---

This facility would consist of an at-grade CDF having a footprint of approximately 14 acres in Slip 1 at the Port of Portland Terminal 4 (**Figure E-1**). A containment berm would be constructed at the mouth of Slip 1 and contaminated sediment would be placed behind the berm. The contaminated sediment would be covered with imported structural fill to the surrounding upland grade. Existing structures within Slip 1 would be demolished and properly removed, and outfalls currently discharging into Slip 1 would be rerouted to the Willamette River (see Appendix B, Drawings C-25 and C-26 for the plan-view layout of the CDF and a generalized cross section through the CDF, respectively).

#### E.1.1.1 Terminal 4 CDF Components

The Terminal 4 CDF would consist of four main components, as follows:

- **CDF Containment Berm.** The CDF containment berm would have a 2 horizontal to 1 vertical (2H:1V) outward-facing slope, and a 1.5H:1V inward-facing slope. The crest of the berm would be constructed to elevation 33 feet National Geodetic Vertical Datum (NGVD). The berm would extend approximately 600 feet across the mouth of the slip and would be approximately 300 feet wide at the base and 20 feet wide at the top. To improve the berm stability, the foundation of the berm would be over-excavated by 5 to 10 feet and backfilled with structural fill. The berm material would consist of sandy gravel or gravelly sand and the training dikes will consist of quarry spalls (**Figure E-1**).
- **Dredged Sediment for Confinement.** The physical and chemical properties of contaminated sediment from sediment management areas (SMAs) within the Portland Harbor Superfund Site would be reviewed for suitability and may be placed in the CDF after being deemed acceptable. Contaminated sediment would be placed in the saturated zone of the CDF to minimize the leachability and

mobility of contaminants; only suitable fill would be placed in the CDF above the water table.

- **Imported Fill.** Imported fill material, including suitable dredged sediment and/or soil, would be placed as cover material above the water table in the CDF to bring the facility up to its design elevation. Imported fill material would be protective of human health and the environment and meet EPA's specific acceptance criteria for imported fill material.
- **CDF Surface Layer.** A 4.5-foot-thick surface layer would be placed above the imported fill layer. This layer would be designed to support the end use of the CDF surface. The layer would likely consist of 4 feet of compacted structural fill with 6 inches of compacted crushed rock, or similar.

### **E1.1.2 Terminal 4 CDF Elevation Control**

The elevation control for the CDF fill sequence would consist of the following:

Approximate Design Elevations (North American Vertical Datum of 1988 [NAVD88])

Base of Slip 1	-31.6 feet
Top of Contaminated Fill	+12.9 feet
Top of Imported Fill	+32.1 feet
Final Elevation	+36.6 feet

Groundwater modeling for this CDF shows that the elevation of permanent saturation in the CDF under critical low-flow conditions, and thus the upper elevation limit for the placement of contaminated sediment, is approximately +12.9 feet NAVD88 (Anchor QEA 2011).

### **E1.1.3 Terminal 4 CDF Capacity**

The total CDF capacity for contaminated fill material (from Portland Harbor SMAs) is 670,000 cy. An additional 610,000 cy of imported fill and surface layers would bring the total CDF volume to 1,280,000 cy. These capacity estimates do not account for the self-weight consolidation of the placed materials as well as the consolidation of the underlying in situ sediment that will be covered by the fill. The design analysis for Terminal 4 estimates that 200,000 cy of capacity for contaminated sediment may be gained due to consolidation of the placed materials and underlying in situ sediment.

## **E2. SHORT-TERM WATER QUALITY EVALUATION**

---

Short-term water quality effects are temporary effects over periods of days and weeks associated with construction activities, and over periods of weeks to months associated with filling operations. These effects may occur during placement of aggregate material in the water column during construction of the berm, discharge of dredging elutriate water over the CDF weir during hydraulic filling, and discharge of groundwater through the berm during hydraulic filling.

The following CDF construction activities were evaluated and would be monitored to minimize potential short-term water quality effects:

- Berm construction
- Elutriate discharge during hydraulic filling
- Short-term groundwater transport through the CDF berm.

### **E2.1 BERM CONSTRUCTION WATER QUALITY**

---

Increased turbidity and suspended sediment concentrations may occur during placement of berm material through the water column at the Terminal 4 CDF. Water quality monitoring (visual, conventional, and contingent laboratory analysis) would occur during berm construction. Appendix E of Terminal 4 Design Analysis Report (Anchor QEA 2011) contains an example of a specific Water Quality Monitoring Plan that is generally consistent with the FS expectations for any CDF in Portland Harbor. Best management practices (BMPs) would be employed during construction to minimize impacts turbidity and suspended sediment. Given the relatively uncontaminated nature of the import materials being placed and the BMPs that would be employed, large-scale or prolonged water quality impacts from construction of the CDF berm would not be expected.

#### **E2.1.1 Effluent Discharge during Hydraulic Filling**

Effluent is defined by the U.S. Army Corps of Engineers (USACE) as water discharged from a CDF during, and as a result of, the filling or disposal of dredged material in the CDF (USACE 2003). Short-Term Groundwater Transport through the CDF Berm. If the CDF is filled using a hydraulic dredge, the dredge slurry would include large quantities of water that would temporarily pond behind the berm, creating a differential hydraulic head across the berm and inducing groundwater flow through the berm toward the river. A short-term groundwater model was developed to assess the potential for accelerated groundwater transport through the berm during hydraulic dredging and filling of the CDF, as described in NewFields (2007a). The model results indicated copper, lead, DDx, and polychlorinated biphenyl (PCB) concentrations would be more than one million times lower than chronic criteria before groundwater enters the river. Therefore, enhanced groundwater flow associated with hydraulic placement of sediment is not expected to be a pathway of concern for any reasonably built CDF at the Site. However,

additional evaluation of potential short-term water quality effects would likely be conducted on a site-specific basis during remedial design if hydraulic dredging in a particular SMA is determined to be a practicable and cost-effective alternative for disposal in a CDF.



## **E3. LONG-TERM WATER QUALITY EVALUATION**

---

The potential for long-term water quality effects at the Site associated with the continuous movement of groundwater through the Terminal 4 CDF fill material and berm was evaluated over periods of years, decades, and centuries.

### **E3.1 LONG-TERM WATER QUALITY CRITERIA**

---

The final application of applicable or relevant and appropriate requirements (ARARs) related to surface water will be established in the Record of Decision (ROD), and the determination of how water quality standards and associated performance standards are applied to a Portland Harbor CDF facility will be finalized at that time. For the current analysis, the long-term water quality numeric criteria were applied without dilution in the water column at an observation point inside the berm (not including the riprap face). Copper benzo(a)pyrene, DDx, and PCBs were evaluated in the long-term model, other contaminants of concern considered for modeling included naphthalene, bis(2-ethylhexyl)phthalate, arsenic, mercury, and three groundwater plume-related volatile organic compounds (VOCs) (benzene, chlorobenzene, and vinyl chloride). Given the large computational and logistical effort involved in this type of modeling, these contaminants were not modeled for the following reasons:

- Naphthalene was not modeled because the initial leachate concentration (0.07 µg/L) is already below the chronic guideline (194 µg/L), thus concentrations at the surface water interface would not exceed the water quality criteria.
- BEHP, arsenic, and mercury are not present at substantially elevated concentrations across large portions of the Site as compared to other contaminants modeled.
- VOCs in general exhibit less persistence in sediments, and it is the heavier, more hydrophobic and recalcitrant compounds that are expected to have the greatest effect on long-term water quality issues in CDFs.

Model predictions of total DDx were compared directly to aquatic life criteria, which are similarly expressed on a total basis. However, fish consumption criteria are evaluated on the basis of individual isomers. As an initial conservative screening evaluation, model predictions for total DDx were compared to the most stringent of the individual fish consumption criteria (4,4'-DDT and 4,4'-DDE). PCBs were modeled as total Aroclors, because chronic aquatic life criteria, fish consumption criteria, and drinking water maximum contaminant levels (MCLs) are all expressed as total PCBs.

#### **E3.1.1 Sequential Batch Leachate Tests**

Sequential Batch Leachate Tests (SBLTs) are laboratory tests designed by the USACE to simulate chemical leaching characteristics of sediment after placement in a CDF

(USACE 2003). These data are used to initialize the source concentrations in the CDF groundwater models. The groundwater models then describe the attenuation processes that potentially occur as the contaminants migrate through the CDF toward the river.

SBLT testing was performed on composite sediment samples from 11 SMAs within Portland Harbor (LWG 2009), and by the Port of Portland using composited sediment from Terminal 4. These 12 SMAs provide a representative cross-section of contaminated sediments throughout the site.

Four sequential leachate cycles were extracted and analyzed for each SMA. A summary of bulk sediment and leachate quality is provided in **Table E-1**. Most organic contaminants are sufficiently hydrophobic that there is negligible change in the bulk sediment concentration between leachate cycles, thus decreasing concentrations were not normally observed. The SBLT tests are also used to develop partitioning coefficients for contaminated sediments from Portland Harbor. The partitioning coefficients describe how readily contaminants are desorbed from the sediments, dissolved in groundwater, and made available for transport through the CDF.

## **E3.2 GROUNDWATER TRANSPORT MODELING**

---

A CDF groundwater contaminant transport model was developed to simulate leaching of contaminants from dredged sediment placed in the Terminal 4 CDF and subsequent transport of contaminants through the berm and the underlying aquifer toward the Site water column (Anchor QEA 2011). A two-dimensional cross-sectional model was aligned with the critical groundwater flow path through the center of the CDF (**Figure E-1**). The following contaminant transport and attenuation processes are included in the model:

- Groundwater advection and dispersion
- Mixing of leachate with incident rainfall above and regional groundwater below
- Adsorption and desorption of contaminants onto berm and aquifer matrix materials
- Biodegradation of contaminants (in some scenarios)

Visual Modflow (Version 2010.1 Pro, Build 4.5.0.157, Waterloo Hydrogeologic, Inc.) was used for model construction, execution, and visualization. All groundwater flow simulations were performed with MODFLOW-2000 (Harbaugh et al. 2000). Contaminant transport simulations were performed with MT3DMS (Zheng and Wang 1999), which uses the flow solution provided by MODFLOW-2000.

The long-term CDF groundwater model simulations were run for 1,000 years, which exceeds the longest applicable engineering design standard being applied to the CDF (defined as a seismic event corresponding to a 10 percent probability of exceedance in 50

years, or a return period of 475 years). In the absence of biodegradation, model predictions were observed to stabilize and approach their asymptotic value by the end of the model simulation period. With biodegradation, the peak and decay of the model prediction curves was well defined over the model simulation period.

### **E3.2.1 Model Structure**

To estimate concentrations of groundwater contaminants at the outer edge of the CDF berm, a two-dimensional (2-D) cross-sectional model was aligned with the critical groundwater flow path through the center of the CDF (**Figure E-2**). **Figure E-2(B)** shows the model grid. The model domain extends 900 feet along the centerline of the CDF. The model extends vertically from elevation -65 to +32 feet NGVD. The contaminated sediment layer extends from the top of the Aquifer (-35 feet NGVD) to the base of the imported fill (+9.5 feet NGVD). The model is discretized into 278 columns and 61 layers. Layer thicknesses range from approximately 1 to 5 feet, and column widths range from approximately 2 to 8 feet. The finest grid spacing is placed over the contact between the contaminated sediments and the berm material, because there are steep gradients in both physical and geochemical properties across this interface.

### **E3.2.2 Boundary Conditions**

The hydrologic boundary conditions are shown on **Figure E-2(C)**. The Willamette River is represented by constant head cells. River stage information was obtained from the U.S. Geological Survey National Streamflow Information Program, station number 14211720 (Morrison Bridge in Portland, Oregon) with a mean annual elevation of +10.5 feet NAVD88.

Transient river stages were used to calibrate model dispersion (see Terminal 4 CDF Design Analysis Report, Appendix A). The transient river boundary is comprised of both seasonal and diurnal tidal fluctuations.

The upgradient head of the CDF is represented by constant head cells. Average groundwater elevations in this area are based on measurements from monitoring wells MW-09 and MW-10 on the Terminal 4 uplands (BBL 2005). A mean annual water level elevation (+16.4 feet NAVD88) was calculated from measurements between September 2004 and September 2005.

A “no-flow” condition was specified along the upriver and downriver boundaries of the modeling domain (i.e., the sides of the 2-D cross section), since these boundaries are aligned parallel to the groundwater flow direction.

Recharge through the Import Fill is a function of annual precipitation, evaporation, transpiration, ground slope, and grain size of the soils, as well as man-made surface structures such as roads, pavement, buildings, and drainage systems. BBL (2005) used the Hydrologic Evaluation of Landfill Performance (HELP) model (Schroeder et al. 1994) to estimate recharge rates at 22.3 and 0.92 inches per year (in/yr) for unpaved and

paved conditions, respectively. The current model simulations conservatively assume an unpaved condition.

The upstream groundwater concentrations in the regional aquifer and the concentrations in the recharge water are assumed to be zero. The source concentrations in the pore water of the contaminated sediment fill are initialized based on SBLT results, and the source concentrations are allowed to decrease over time as contaminants are progressively desorbed from the sediments. For most of the hydrophobic contaminants being evaluated in the absence of biodegradation, the contaminant reduction rates are so slow that the contaminated sediment fill essentially behaves as an infinite source over the model simulation period.

### **E3.2.3 Groundwater Model Input Parameters**

Physical and hydrogeologic input parameters are compiled in **Table E-2**, including mean or central tendency values for use in base case model simulations, and a representative range of values (minimum and maximum values) for use in sensitivity and uncertainty analysis. Geochemical input parameters for Terminal 4 CDF contaminants are compiled in **Table E-3**. Data sources and rationale are also summarized in these tables.

The values used in the CDF groundwater modeling are generally consistent with the values used in the Portland Harbor surface water and cap models, with certain exceptions that are specific to the nature of the CDF groundwater modeling. For example, partitioning coefficients used in the CDF groundwater model for contaminated dredged sediment are derived from anaerobic sequential batch leaching tests, laboratory tests designed specifically for simulating geochemical conditions in a CDF. Partitioning coefficients used in the CDF berm were derived from Portland Harbor RI literature values and water-column data, consistent with the values used in both surface water and cap models. CDF model scenarios were run with and without biodegradation, using conservatively slow rates, because of the long timeframe (1,000 years) of the model as compared to the timeframes for the other modeling efforts.

An overview of key model input parameters is provided below.

### **E3.2.4 Hydrogeologic Parameters**

The material and hydraulic properties of the CDF building materials, including the contaminated sediment fill material, cover material (imported fill), regional aquifer, berm fill, and the training dikes, are summarized in **Table E-2**. Representative values for organic carbon content for contaminated sediment fill material were derived from bulk sediment testing from the FS database (LWG 2009). Representative values for organic carbon content for import fill and berm fill material were derived from test results from local quarries (Anchor 2007a). Hydraulic conductivity values for contaminated sediment fill material were derived from consolidation tests conducted at Terminal 4 and other Region 10 sites; these tests simulate the reduction in porosity and permeability that result from the self-weight and overburden pressures in a CDF (Anchor 2007b). Hydraulic

conductivity values for local aquifer materials were derived from Terminal 4 pumping tests (Hart Crowser 2000), and representative literature values were used to characterize import fill and berm fill material based on their grain size specifications (Freeze and Cherry 1979). Values for horizontal and vertical dispersion were obtained from dynamic model calibration, in response to daily and seasonal water level fluctuations in the river (NewFields 2007a).

### **E3.2.5 Initial Source Concentrations**

The initial source concentrations for the various groundwater contaminants are compiled in **Table E-3**. The geometric mean, arithmetic mean, and 90th percentile leachate concentrations from Portland Harbor SBLT results (excluding leachate results from sediment decision units [SDUs] RM6W and RM7W) were selected to represent the initial conditions in the groundwater model, including the base case (central value), as well as the range of concentrations (minimum and maximum values) to be used in sensitivity and uncertainty analyses. Because the CDF is comprised of a mixture of sediment and leachate from a variety of different SDUs, the arithmetic mean was used to characterize the source strength of this material. This does not imply that the sediments will be homogeneously mixed during placement, but rather that CDF groundwater will be exposed to sediments from a variety of different SDUs as it migrates through the CDF.

### **E3.2.6 Partitioning Coefficients**

The ratio of the bulk sediment concentration to the SBLT leachate concentration was used to develop site-specific partitioning coefficients for Portland Harbor contaminated sediments (**Table E-3**). The derivation of partitioning coefficients from SBLT tests is presented in Appendix A of the Terminal 4 CDF Design Analysis Report (Anchor QEA 2011). For most contaminants, the geometric mean value of the partitioning coefficients from the ten SMAs was used as the base case value, the coefficient for total PCBs was derived from a linear isotherm model because total PCB data are well described by this type of model.

The SBLT leachate results are applicable to the contaminated sediment material, but are not representative of the geochemical environment in the berm. The physical properties (sand and gravel) and source characteristics (regional quarries) of the berm material are fundamentally different, as are the geochemical conditions in the berm (i.e., dominated by adsorption processes rather than desorption). Applicable partitioning coefficients for metals in the berm material were established in NewFields (2007b). However, the minimum organic carbon partitioning coefficient ( $K_{oc}$ ) value for DDD was revised based on site-specific Willamette River water column data.

While the partitioning coefficients used to model the confined contaminated sediments in the CDF are based on site-specific anaerobic leaching tests, the partitioning coefficients used for modeling contaminant movement through the berm are essentially the same as those used in the sediment cap model based on Portland Harbor literature data and water-column analyses. However, the partitioning coefficient for copper used in the CDF

models is lower (more conservative) than the value used for the surface water and cap models because of the decreased adsorptive capacity of the suitable imported sandy material that is expected to be used for CDF berm construction.

### **E3.2.7 Biodegradation Rates**

Biodegradation rates used in the Terminal 4 CDF model (expressed as half-lives, in days) are presented in **Table E-3**, along with supporting literature citations. It is expected that anaerobic degradation processes will prevail in the confined contaminated sediments, whereas aerobic degradation processes will be more important in the berm. The Terminal 4 CDF model was set to zero degradation as a base case scenario, and also provides alternative scenarios with conservatively protective biodegradation rates from the lower end of published literature values, with particular emphasis on field and regional studies. A detailed discussion of the literature supporting the biodegradation rates selected for use in the Terminal 4 CDF model are provided in the Terminal 4 CDF Design Analysis Report (Anchor QEA 2011).

### **E3.2.8 Long-Term Groundwater Model Results**

#### **E3.2.8.1 Groundwater Flow Characteristics**

Groundwater transport pathways and residence times in the contaminated sediments are shown on **Figure E-3**. Transport pathways are dominated by downward vertical flow through the contaminated sediment toward the underlying aquifer and laterally into the berm. This results from mounding of infiltrated rainwater at the contact between the Sediment Fill and the Imported Fill, near elevation +9.5 feet NGVD. Once groundwater leaves the CDF, it is shown flowing horizontally toward the river in the underlying aquifer, and then upwelling into the berm and training dikes along the contact with the contaminated sediments.

The groundwater residence time in the contaminated sediments varies from less than 20 years along the front and bottom of the CDF, to greater than 200 years at the upper rear of the CDF (**Figure E-3**). As a result, contaminated sediments in the upper rear of the CDF are likely to have less effect on potential groundwater exit concentrations.

#### **E3.2.8.2 Long-Term Groundwater Quality Predictions**

**Figures E-4(a through d)** present the predicted CDF groundwater exit concentrations copper, benzo(a)pyrene, DDX, and PCBs. These charts show the model prediction curves over 1,000-year simulation periods. By comparison, the longest applicable engineering design standard being applied to the CDF (the seismic design standard) has a return period of 475 years.

Model predictions are compared to the CDF performance standards (USEPA 2010a) and various regulatory criteria. Note that the selection of water quality criteria was ongoing at the time the modeling was performed. Chronic ambient water quality criteria was not established for benzo(a)pyrene at the time of modeling, and the value used (0.96 µg/L) is

based on EPA guidance (USEPA 2003). The maximum concentration predicted by the CDF model for this constituent is below chronic guidelines.

Prediction curves are presented for the peak centerline concentration, as well as the spatially averaged concentration over the interface between the berm and the river. The region at or below analytical reporting limits is shaded in gray, and the region at or below ambient background concentrations is shaded in yellow. For organic contaminants, model predictions are presented for a scenario with no biodegradation, and an alternative scenario assuming a conservatively slow rate of biodegradation based on peer-reviewed literature studies.

**Copper (Figure E-4a).** Centerline copper concentrations are below both chronic water quality criteria and upstream background concentrations during the 1,000-year model simulation period.

**Benzo(a)pyrene (Figure E-4b).** The benzo(a)pyrene centerline concentration remains well below the chronic guideline, and the spatially averaged concentration remains well below the MCL and fish consumption criterion during the 1,000-year model simulation period. The model predicted concentrations are also below the analytical reporting limit. For comparison, model predictions using a conservative biodegradation rate (assuming a 41-year half-life) are also presented; benzo(a)pyrene concentrations are many orders of magnitude below all water quality criteria.

**DDx (Figure E-4c).** The DDx centerline concentration remains below the chronic water quality criteria, and the spatially averaged concentration remains below the fish consumption criteria during the 1,000-year simulation period. The model predicted concentrations are also below the analytical reporting limit. For comparison, model predictions using a conservative biodegradation rate (assuming a 90-year half-life) are also presented; DDx concentrations are many orders of magnitude below all water quality criteria.

**PCBs (Figure E-4d).** PCB centerline concentrations remain below the chronic water quality criteria, and spatially averaged concentrations remain below the MCL during the 1,000-year simulation period. Spatially averaged PCB concentrations also remain below the fish consumption criterion for approximately 500 years, assuming zero biodegradation, and below the upstream background concentration and the analytical reporting limit for approximately 600 years. Model predictions using a biodegradation rate (assuming a 60-year half-life) indicate total PCB concentrations are orders of magnitude below all water quality criteria at all times. Assuming a biodegradation half-life of 205 years, PCB concentration in groundwater exiting the berm will meet water quality criteria indefinitely.

**Select Contaminant Transport Pathways.** The contaminant distributions and transport pathways for DDx and PCBs in groundwater migrating through the CDF berm at Year 475 are shown on **Figure E-5**. Although the absolute concentrations and travel times will differ, the relative distributions and pathways will be similar for other contaminants as

well, since they are fundamentally controlled by the same processes. In general, the fine-grained and consolidated dredged sediment in the CDF serves as a plug, causing regional groundwater to flow around and under the facility, and then upwell into the more permeable berm. Contaminants diffuse out from the contaminated sediment along the base of the CDF and along the inner berm face, and are then advected toward the river with the upwelling regional groundwater flow regime. The training dikes provide preferential transport pathways across the berm, because they are an order of magnitude more permeable than the berm fill material. As a result, the leading edge of the potential groundwater plume, as well as the peak concentrations, occurs within the upper training dike on the outer berm face.



## **E4. REFERENCES**

---

- Anchor. 2007a. Borrow source analytical results. June 8, 2007.
- Anchor. 2007b. Technical Memorandum: Dredged material permeability evaluation for Portland Harbor sediments. May 4, 2007.
- Anchor QEA. 2011. Terminal 4 Confined Disposal Facility Design Analysis Report, prepared for the Port of Portland.
- Blasland, Bouck & Lee, Inc. (BBL). 2005. Terminal 4 Early Action Engineering Evaluation/Cost Analysis, Public Review Draft. Port of Portland, Portland Oregon.
- Bridgewater Group. 2002. Phase IB and II Soil and Groundwater Sampling Results, Portland Shipyard Remedial Investigation. Prepared for the Port of Portland. June 25, 2002.
- Freeze, R.A., and Cherry, J.A. 1979. Groundwater. Prentice Hall, 604 pages.
- Harbaugh, A.W., Banta, E.R., Hill, M.C., and M.G. McDonald. 2000. MODFLOW-2000, the U.S. Geological Survey modular ground-water model—User guide to modularization concepts and the Ground-Water Flow Process: U.S. Geological Survey Open-File Report 00-92, 121 pages.
- Hart Crowser. 2000. Remedial Investigation Report, Terminal 4, Slip 3 Upland. Port of Portland, Portland, Oregon. January 2000.
- Lower Willamette Group (LWG). 2009. Portland Harbor Superfund Site Draft Remedial Investigation Report. October 2009.
- NewFields. 2007a. Technical Memorandum: Explanation of Effective Dispersion Calculation. Prepared for USEPA, Region 10. April 4.
- NewFields. 2007b. Technical Memorandum: Cadmium, copper, and lead partition coefficients for berm materials in Terminal 4 CDF groundwater transport models. June 20, 2007.
- Schroeder et al, 1994. Hydrologic Evaluation of Landfill Performance (HELP) model.
- Snyder, D.T., D.S. Morgan and T.S. McGrath. 1994. Estimation of Ground-Water Recharge from Precipitation into Drywells, and On-Site Waste-Disposal Systems in the Portland Basin, Oregon and Washington, U.S. Geological Survey Water-Resources Investigations Report 92-4010, Portland, Oregon, 40p.
- Spitz, K., and J. Moreno. 1996. A Practical Guide to Groundwater and Solute Transport Modeling, John-Wiley and Sons, New York, 461 pp.

- USACE. 1987. Engineering and Design – Confined Disposal of Dredged Material. Engineer Manual 1110-2-5027. US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. September 30, 1987.
- USACE. 2003. Evaluation Of Dredged Material Proposed For Disposal At Island, Nearshore, Or Upland Confined Disposal Facilities - Testing Manual (Upland Testing Manual). Technical Report ERDC/EL TR-03-1, U.S. Army Engineer Research and Development Center, Vicksburg, MS. <http://el.erdc.usace.army.mil/dots/pdfs/trel03-1.pdf>
- USACE et al. (U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, and others). 2009. Sediment Evaluation Framework for the Pacific Northwest. May 2009.
- USEPA. 2003. Procedures for Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: PAH Mixtures. Office of Research and Development, EPA-600-R-02-013.
- USEPA. 2010a. Letter to the Lower Willamette Group from the U.S. Environmental Protection Agency regarding USEPA Performance Standards for Confined Disposal Facilities for the Portland Harbor Feasibility Study. February 18, 2010.
- Vaccaro, J.J., D.G. Woodward, M.W. Gannett, M.A. Jones, C.A. Collins, R.R. Caldwell, and A.J. Hansen. 1997. Summary of the Puget-Willamette Lowland Regional Aquifer-System Analysis, Washington, Oregon, and British Columbia, U.S. Geological Survey Open-File Report 96-353, Tacoma, Washington, 54 p.
- Zheng, Chunmiao and P. Patrick Wang. 1999. MT3DMS, A modular three-dimensional multi-species transport model for simulation of advection, dispersion and chemical reactions of contaminants in groundwater systems; documentation and user's guide, U.S. Army Engineer Research and Development Center Contract Report SERDP-99-1, Vicksburg, MS, 202 p.
- Wei, Norman S. 2005. "Understanding the Mixing Zone Concept," *Pollution Engineering*. June 1, 2005.  
(<http://www.pollutionengineering.com/Articles/Column/af98a02711e68010VgnVCM100000f932a8c0>)

## Tables

*This page left blank intentionally.*

Table E-1. Bulk Sediment and Leachate Quality

Sediment Decision Unit	Copper			Benzo(a)pyrene			Naphthalene			Total PCBs			Total DDx							
	Bulk Sediment Conc.	Mean Leachate Conc.	Mean Log Kd	Bulk Sediment Conc.	Mean Leachate Conc.	Mean Log Koc	Bulk Sediment Conc.	Mean Leachate Conc.	Mean Log Koc	Bulk Sediment Conc.	Mean Leachate Conc.	Mean Log Koc	Bulk Sediment Conc.	Mean Leachate Conc.	Mean Log Koc					
	mg/kg	mg/L	Log(L/kg)	µg/kg	µg/L	Log(L/kg)	µg/kg	µg/L	Log(L/kg)	µg/kg	µg/L	Log(L/kg)	µg/kg	µg/L	Log(L/kg)					
RM2E	16.6	J	0.0062	3.42	100		0.051	5.24	11		0.048	4.29	109		0.366	4.40	6.1	U	0.005	ND
RM3.5E	33.6	J	0.0085	3.60	460		0.286	5.03	150		0.015	5.81	4,520		3.763	4.90	10.0	U	0.011	ND
RM4.5E	48.9		0.0086	3.75	7,900		0.050	7.01	250		0.050	5.50	46		0.089	4.51	23.0	U	0.011	ND
RM5W	121.0	J	0.0033	4.56	450		0.572	5.04	27		0.011	5.53	10	U	0.009	ND	2.0	U	0.005	ND
RM5.5E	20.8	J	0.0018	4.06	240	J	0.310	4.75	73		0.228	4.27	10	U	0.070	ND	6.1		0.024	4.23
RM6.5E	67.6	J	0.0066	4.01	200	J	0.253	4.42	240	J	0.121	4.83	77		0.095	4.44	16.8		0.017	4.53
SwanIs	67.8	J	0.0037	4.27	70		0.039	5.17	6		0.029	4.22	50		0.088	4.66	2.0	U	0.005	ND
SwanIs	14.5	J	0.0034	3.62	74		0.050	4.94	35		0.022	NC	69		0.163	4.39	1.9	U	0.005	ND
RM9W	50.6		0.0033	4.19	72	J	0.049	4.93	36		0.027	4.89	1,358		1.315	4.78	238.0		0.302	4.66
RM9W	28.7	T	0.0025	4.06	290		0.138	5.31	65		0.025	5.40	281		1.192	4.32	264.5		0.023	6.06
RM6W	33.6	J	0.0039	3.94	200,000		54.391	4.54	3,200,000		6,567.530	3.65	120	U	0.044	ND	99.0	U	0.023	ND
RM7W	70.4		0.0036	4.29	800	J	0.221	5.26	190		1.337	3.79	990	U	2.549	ND	46,000		40.662	4.75

Notes:  
J = Estimated value  
ND = Koc not calculated because constituent is undetected in bulk sediment  
U = Undetected at indicated reporting limit  
Mean leachate concentration is geometric mean of four leachate cycles; nondetects included at 1/2 reporting limit value  
Sites RM6W and RM7W are excluded from CDF model input values  
Total DDx is defined as the sum of 4,4’ -DDT, 4,4’ -DDD, and 4,4’ -DDE

**Table E-2. Physical and Hydraulic Properties of CDF Materials for the Terminal 4 CDF Model**

Material	Units	Model Input Values for Base Case and Sensitivity Analysis			Data Source/Rationale
		Min.	Central	Max.	
Sediment Fill					
Fraction organic carbon	-	0.010	0.015	0.018	LWG (2009), Measured pH bulk sediment: 10% / Average / 90%
Porosity	-	-	0.35	-	Anchor (2006b)
Hydraulic conductivity	ft/d	0.00017	0.00085	0.0028	Anchor (2007c); Consolidation tests from T4 and Region 10
Bulk density	g/cm <sup>3</sup>	-	1.3	-	BBL (2005; Table 4-4); Consolidation tests from T4
Imported Fill					
Fraction organic carbon	-	0.0005	0.0006	0.0007	Anchor (2007b), Measured import from local quarries
Porosity	-	-	0.30	-	Anchor (2006b)
Hydraulic conductivity	ft/d	-	28	-	Freeze and Cherry (1979; Table 2.2); clean sand
Bulk density	g/cm <sup>3</sup>	-	2.0	-	Holz and Kovacs (1981; Table 2-1)
Berm Fill					
Fraction organic carbon	-	0.0005	0.0006	0.0007	Anchor (2007b), Measured import from local quarries
Porosity	-	-	0.30	-	Anchor (2006b)
Hydraulic conductivity	ft/d	30	280	450	Hazen's approximation based on gradation specification for Select Fill
Bulk density	g/cm <sup>3</sup>	-	2.0	-	Holz and Kovacs (1981; Table 2-1)
Dispersion - Horizontal	-	-	40	-	Anchor (2006b); NewFields (2007a): Dynamic model calibration
Dispersion - Vertical	-	-	0.4	-	Anchor (2006b); NewFields (2007a): Dynamic model calibration
Training Dikes					
Fraction organic carbon	-	-	0.00006	-	Assumed 10 percent of Berm Fill value
Porosity	-	-	0.30	-	Anchor (2006b)
Hydraulic conductivity	ft/d	-	2,800	-	Freeze and Cherry (1979; Table 2.2); clean gravel
Bulk density	g/cm <sup>3</sup>	-	2.2	-	Holz and Kovacs (1981; Table 2-1)
Aquifer					
Fraction organic carbon	-	-	0.003	-	BBL (2005); Average measured value in Slip 1 aquifer material
Porosity	-	-	0.30	-	Anchor (2006b)
Hydraulic conductivity (K)	ft/d	-	65	-	Hart Crowser (2000); Pumping test results, as reported in BBL (2005)
Bulk Density	g/cm <sup>3</sup>	-	2.0	-	Holz and Kovacs (1981; Table 2-1)

Note:

"Base case" input values used in Figures 6-2A through 6-2E

**DO NOT QUOTE OR CITE**

**This document is currently under review by US EPA and its federal, state, and tribal partners, and is subject to change in whole or in part**

**Table E-3. Geochemical Properties of Chemicals of Concern for the Terminal 4 CDF Model**

Material	Units	Model Input Values for Base Case and Sensitivity Analysis			Data Source/Rationale
		Min.	Central	Max.	
Initial Source Concentrations in Contaminated Sediment Pore Waters					
Copper	µg/L	4	8	14	LWG (2009); Geometric Mean, Arithmetic Mean, and 90th Percentile of SBLT results
Benzo(a)pyrene	µg/L	0.12	0.23	0.52	LWG (2009); Geometric Mean, Arithmetic Mean, and 90th Percentile of SBLT results
Total DDX	µg/L	0.014	0.058	0.076	LWG (2009); Geometric Mean, Arithmetic Mean, and 90th Percentile of SBLT results
Total PCB Aroclors	µg/L	0.22	0.87	2.17	LWG (2009); Geometric Mean, Arithmetic Mean, and 90th Percentile of SBLT results
Metal Partitioning Coefficient [Kd]					
Copper [Sediment]	L/kg	-	8,900	-	Anchor QEA and Newfields (2010); LWG (2009); Geometric Mean of AOPCs
Copper [Berm, Cap]	L/kg	100	165	-	NewFields (2007b)
Copper [Quarry Spall]	L/kg	1	20	-	USEPA (2005; Table 3); Minimum and 1st Percentile Kd
Log Organic Partitioning Coefficient [Koc] - Sediment					
Benzo(a)pyrene	Log L/kg-OC	-	5.18	-	Anchor QEA and Newfields (2010); LWG (2009); Geometric Mean of AOPCs
Total DDX	Log L/kg-OC	-	4.87	-	Anchor QEA and Newfields (2010); LWG (2009); Geometric Mean of AOPCs
Total PCB Aroclors	Log L/kg-OC	-	4.86	-	Anchor QEA and Newfields (2010); LWG (2009); Linear Isotherm Model
Log Organic Partitioning Coefficient [Koc] - Berm					
Benzo(a)pyrene	Log L/kg-OC	5.68	6.01	6.67	LWG RI Report Table E6 (2009)
Total DDX	Log L/kg-OC	5.69	6.44	6.62	LWG RI Report Table E6 (2009); Geometric Mean of DDT, DDE, and DDD
Total PCB Aroclors	Log L/kg-OC	5.96	6.39	7.59	LWG RI Report Table E6 (2009); Geometric Mean of Ar-1254 and Ar-1260
Biodegradation Half Life in Sediment [Anaerobic]					
Benzo(a)pyrene	days	-	15,000	Infinite <sup>[1]</sup>	Central value = 95% UCL from Bach et al. (2005); Coates et al. (1996a, 1996b, 1997); Chang et al. (2001); Heitkamp & Cerniglia (1987); Rothermich et al. (2002)
Total DDX	days	-	33,000	Infinite <sup>[1]</sup>	Eganhouse et al. (2000a, 2000b)
Total PCB Aroclors	days	-	22,000	Infinite <sup>[1]</sup>	Magar et al. (2005); van Dort et al. (1997); Mackay et al. (1994); Davis (2004)

Notes:

[1] Infinite half life corresponds to zero biodegradation

"Base case" input values used in Figures 6-2A through 6-2E

**DO NOT QUOTE OR CITE**

**This document is currently under review by US EPA and its federal, state, and tribal partners, and is subject to change in whole or in part**

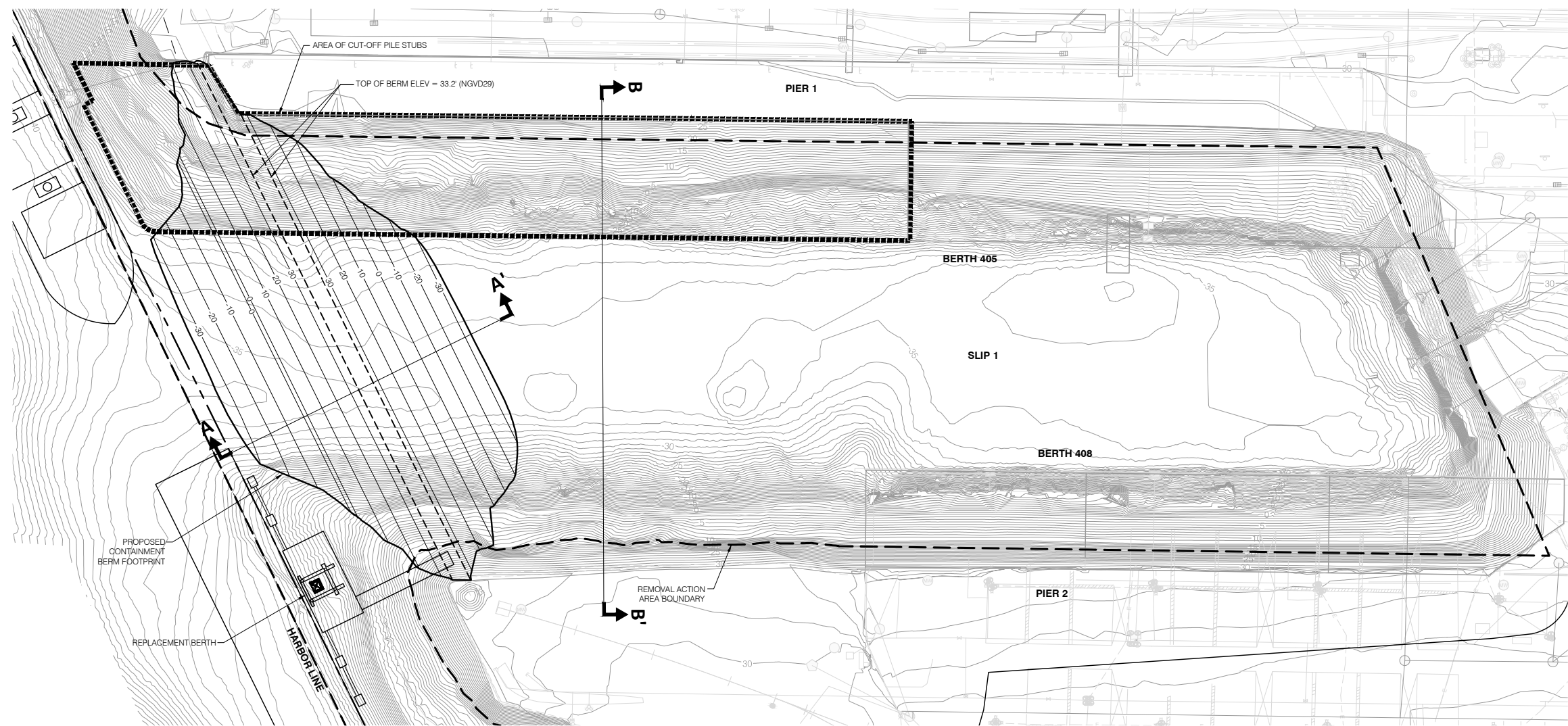
*This page left blank intentionally.*



## Figures

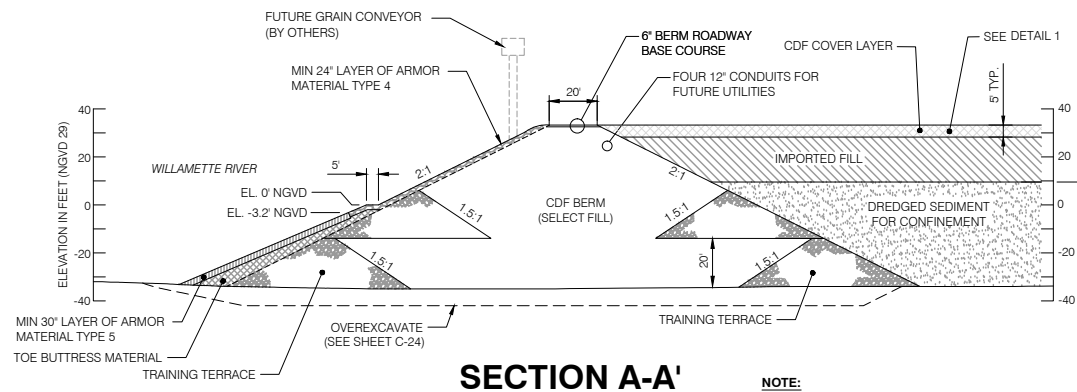
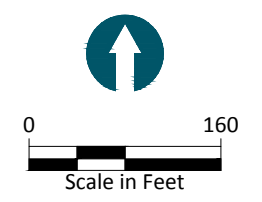
*This page left blank intentionally.*

K:\Projects\0142-LWG PRP Consortium\WG Feasibility Study\0142-RP-009.dwg Figure 1  
Mar 16, 2012 9:02am heriksen



**NOTES:**

1. NGVD29 - National Geodetic Vertical Datum of 1929  
NAVD88 - North American Vertical Datum of 1988
2. HORIZONTAL DATUM: PORT OF PORTLAND  
LOCAL PROJECTION (INTERNATIONAL FEET)  
VERTICAL DATUM: NGVD 29-47  
CONTOUR INTERVAL = 1 FT
2. AT THIS LOCATION, THE CONVERSION FROM NGVD29 TO NAVD88 IS 3.4 FEET. THEREFORE, THE ELEVATION OF THE TOP OF THE CAP IS +33.2 FEET NGVD29 (+36.6 FEET NAVD88) AND THE MAXIMUM ELEVATION FOR THE PLACEMENT OF DREDGED SEDIMENT FOR CONFINEMENT IS +9.5 FEET NGVD29 (+12.9 FEET NAVD88).

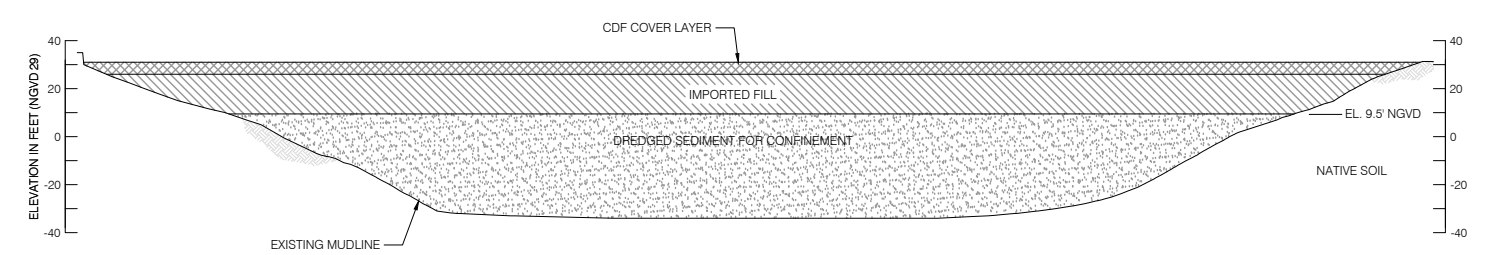


**SECTION A-A'**



**NOTE:**

CONTRACTOR CAN USE TRAINING TERRACES TO BUILD THE BERM. THE TERRACES SHALL EACH BE 20' IN HEIGHT. SEE SPECIFICATIONS FOR MORE DETAILS.



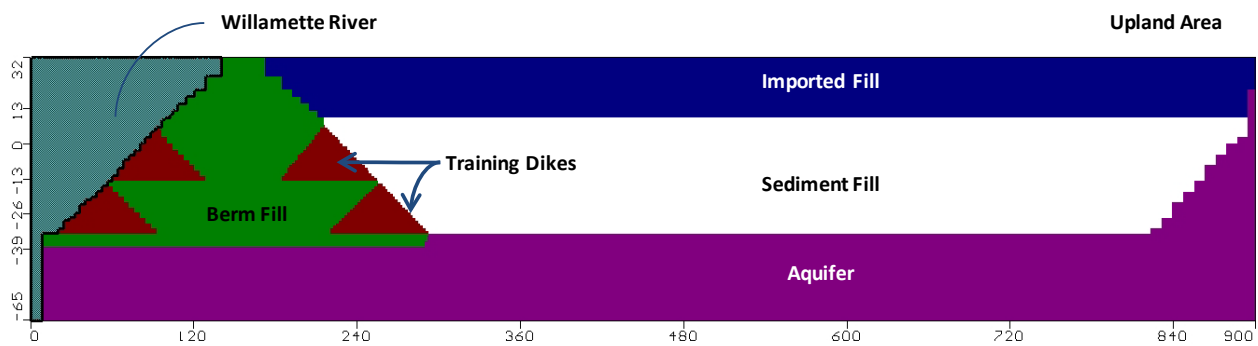
**SECTION B-B'**



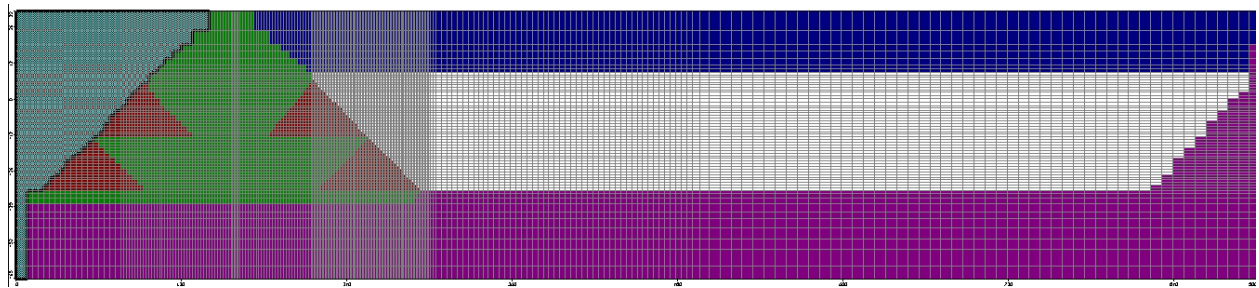
DO NOT QUOTE OR CITE  
This document is currently under review by US EPA  
and its federal, state, and tribal partners, and is  
subject to change in whole or in part

Figure E-1  
**Portland Harbor RI/FS**  
Draft Feasibility Study  
Terminal 4 CDF Plan View And Sections

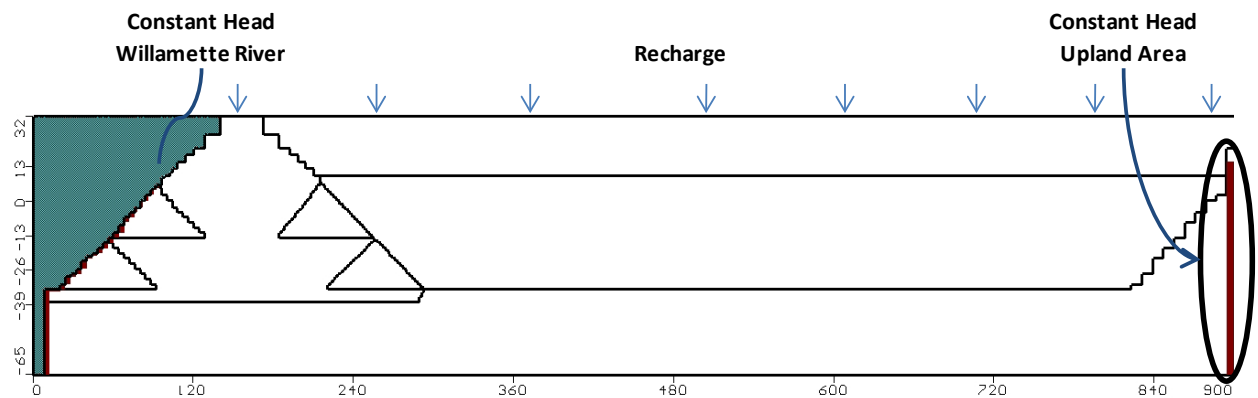
*This page left blank intentionally.*



**A. Key Hydrogeologic Units**

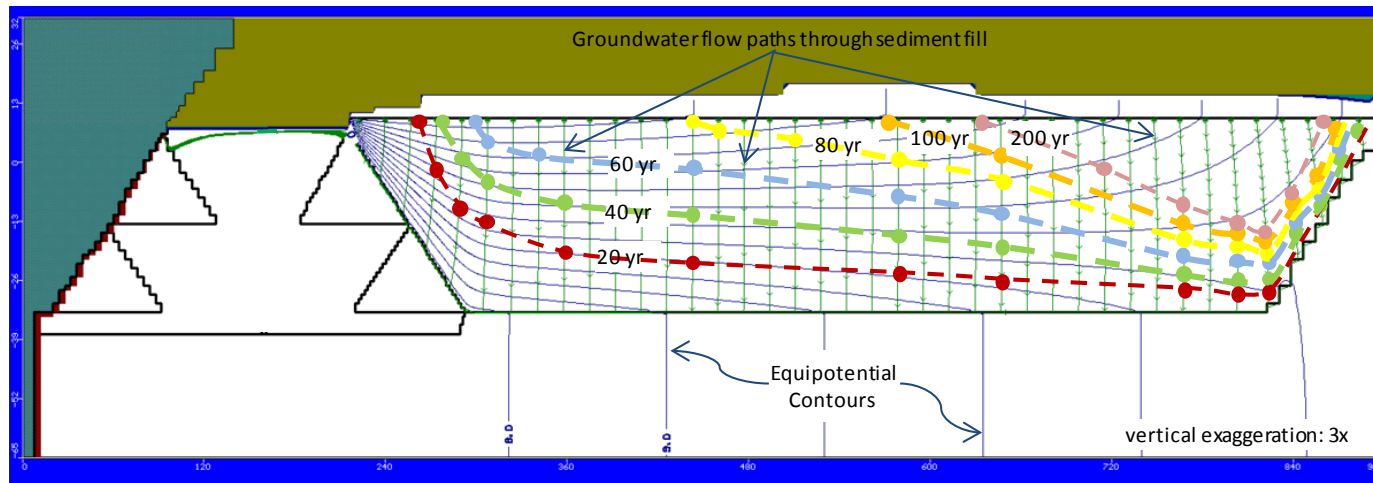


**B. Model Grid**

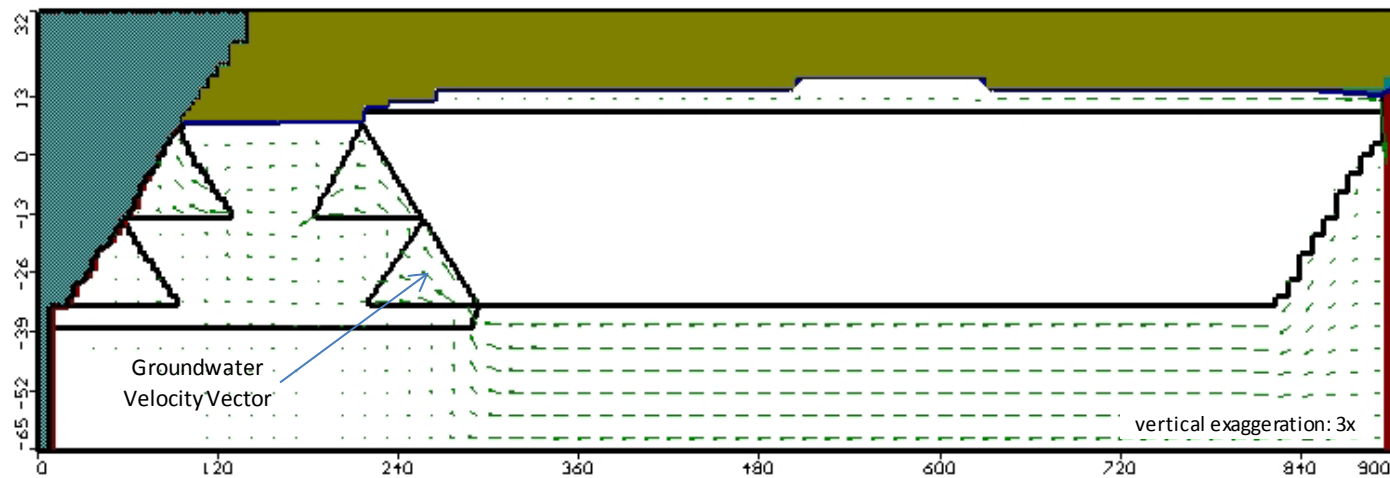


**C. Boundary Conditions**

*This page left blank intentionally.*



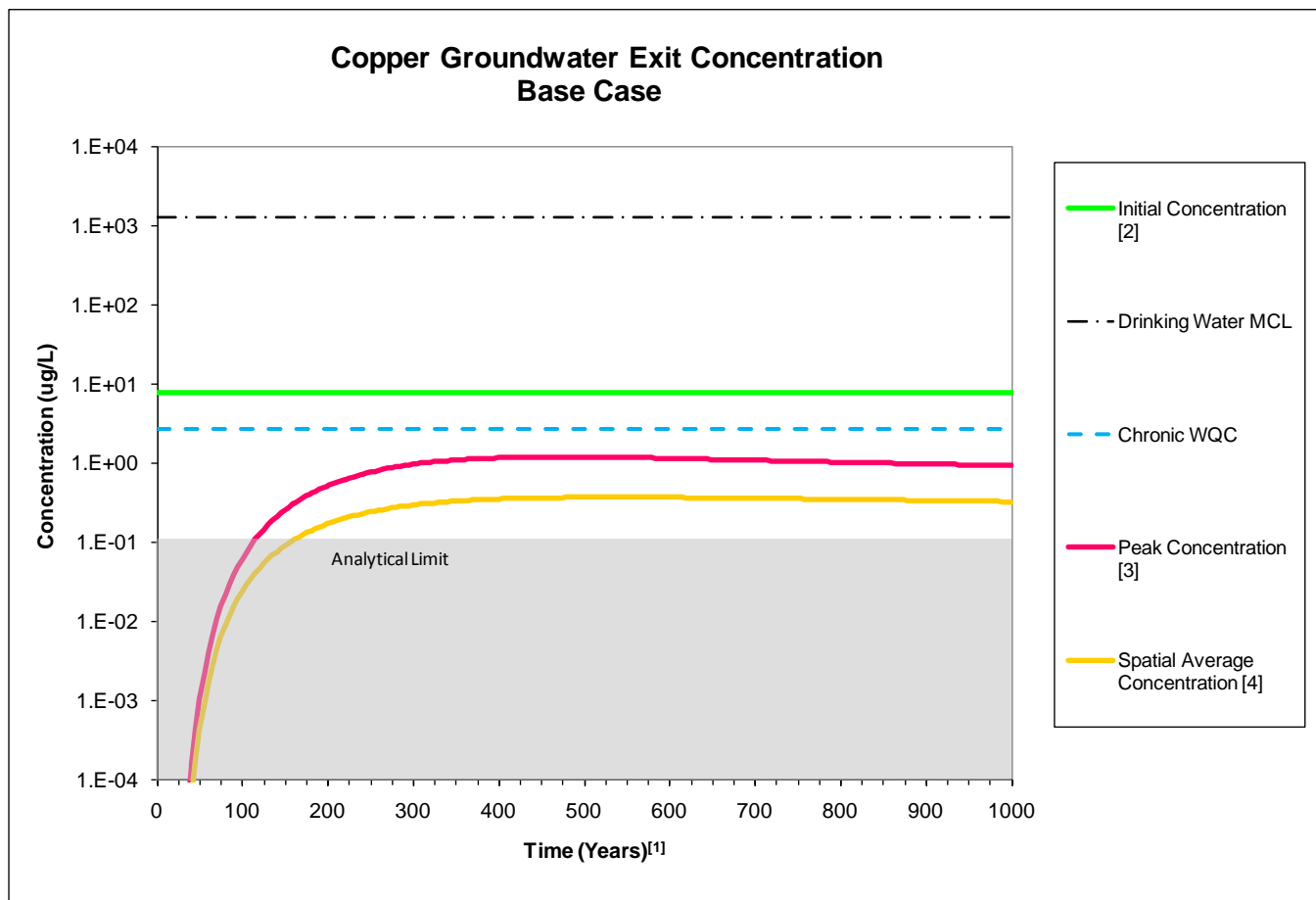
**A. Groundwater Flow Paths and Residence Times**



**B. Groundwater Velocity Vectors**

*This page left blank intentionally.*



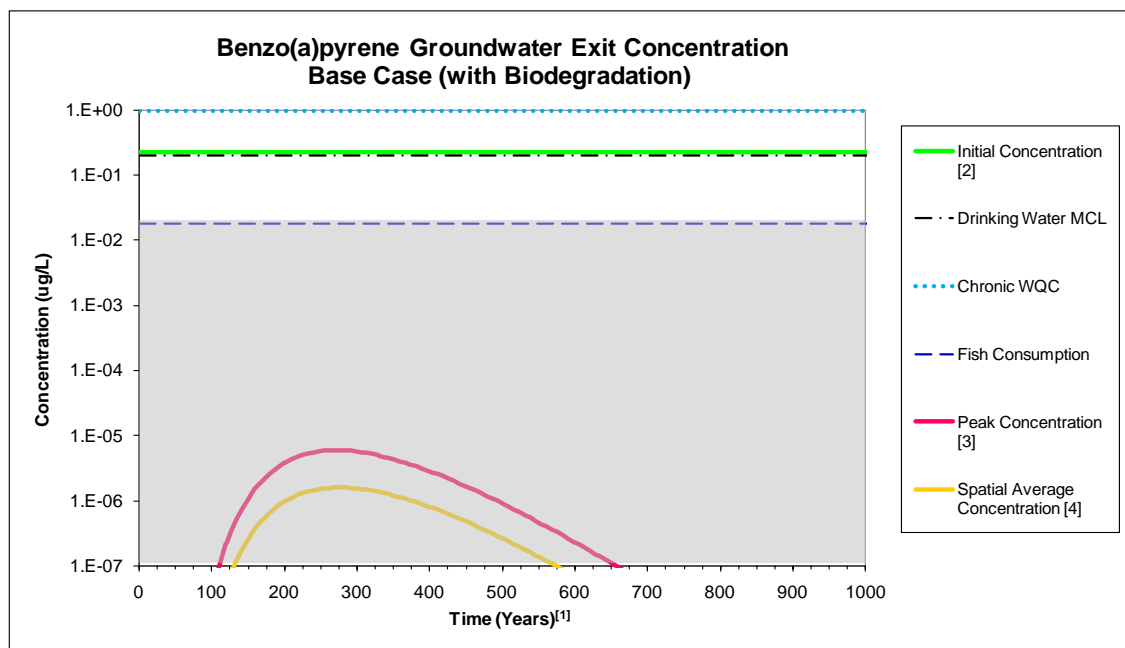
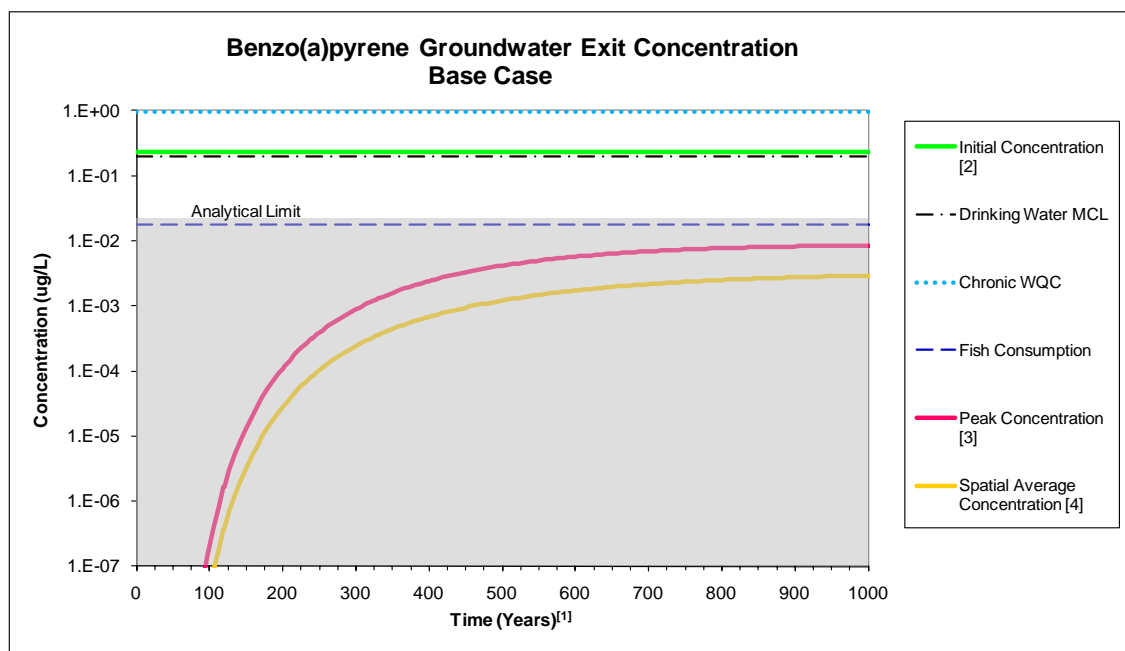


**Notes:**

Groundwater observation point is the predicted concentration in last model cell adjacent to river boundary, approximately one foot below the berm face.

- [1] Time zero refers to the time when CDF construction is complete. It may take up to 4 to 6 years to fill and cover the CDF.
- [2] Initial Concentration = sediment leachate concentration in CDF estimated using SBLT test results; see Appendix A and Table 6-7.
- [3] Peak Concentration = peak contaminant concentration in groundwater exiting the CDF berm.
- [4] Spatial Average Concentration = average contaminant concentration in groundwater exiting the CDF berm averaged vertically over the CDF berm face.

*This page left blank intentionally.*

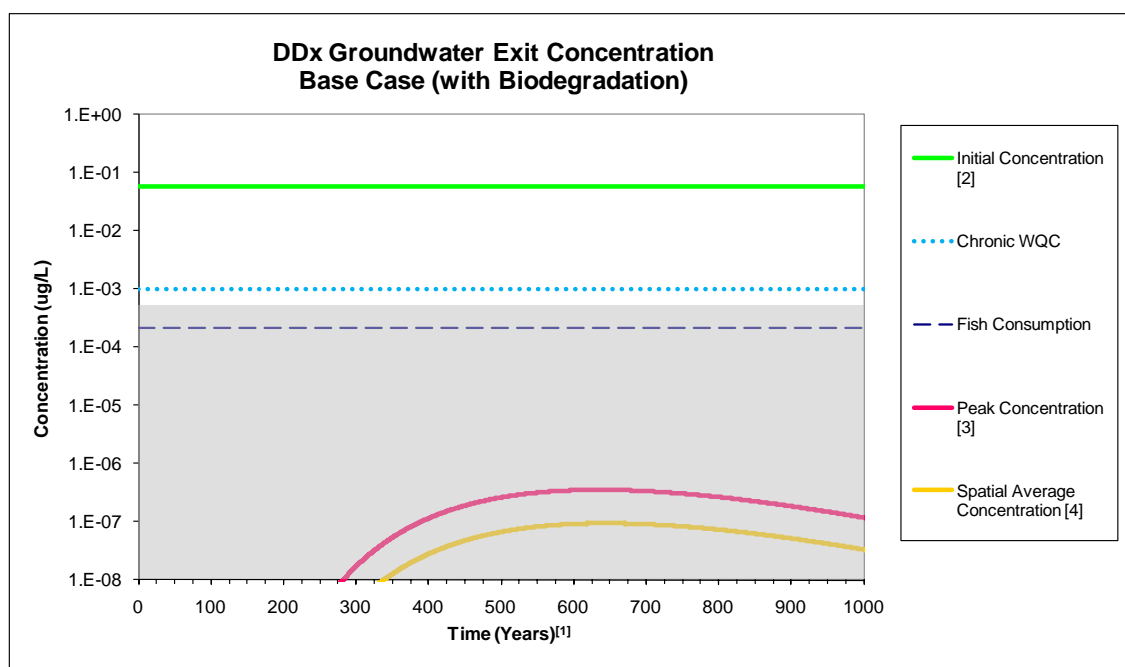
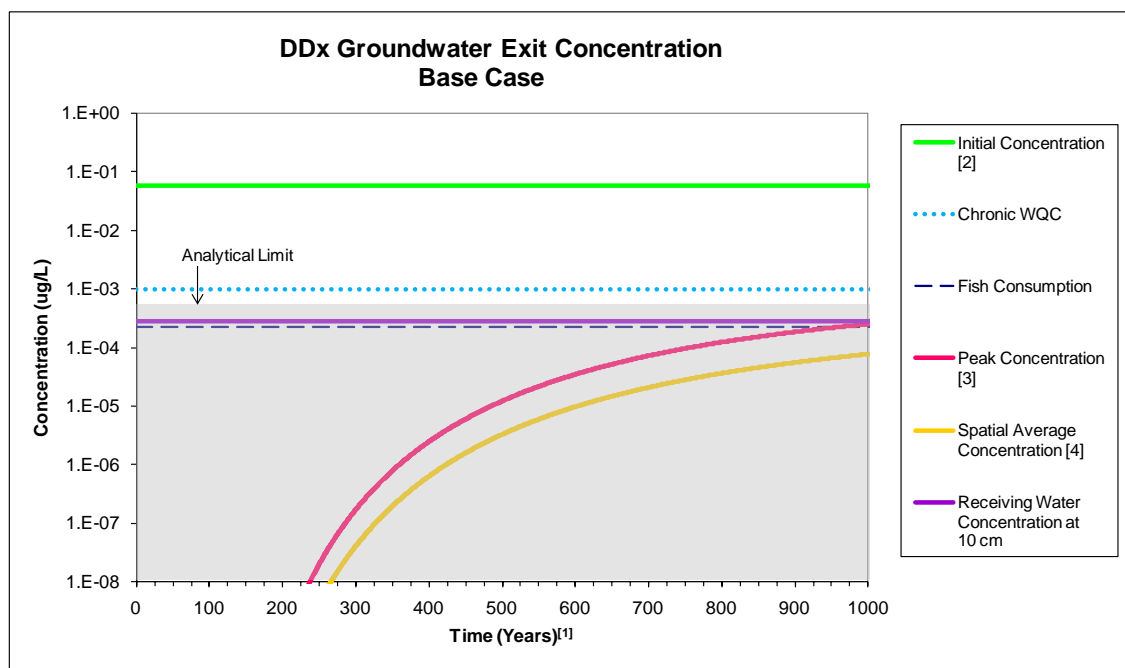


**Notes:**

Groundwater observation point is the predicted concentration in last model cell adjacent to river boundary, approximately one foot below the berm face.

- [1] Time zero refers to the time when CDF construction is complete. It may take up to 4 to 6 years to fill and cover the CDF.
- [2] Initial Concentration = sediment leachate concentration in CDF estimated using SBLT test results; see Appendix A and Table 6-7.
- [3] Peak Concentration = peak contaminant concentration in groundwater exiting the CDF berm.
- [4] Spatial Average Concentration = average contaminant concentration in groundwater exiting the CDF berm averaged vertically over the CDF berm face.

*This page left blank intentionally.*

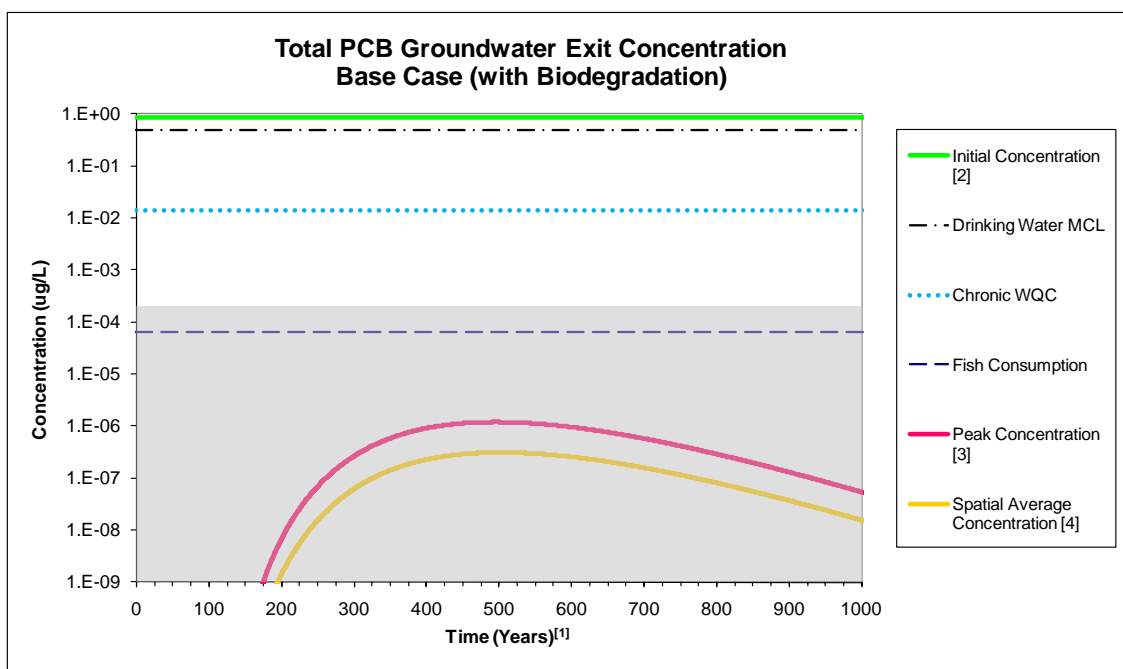
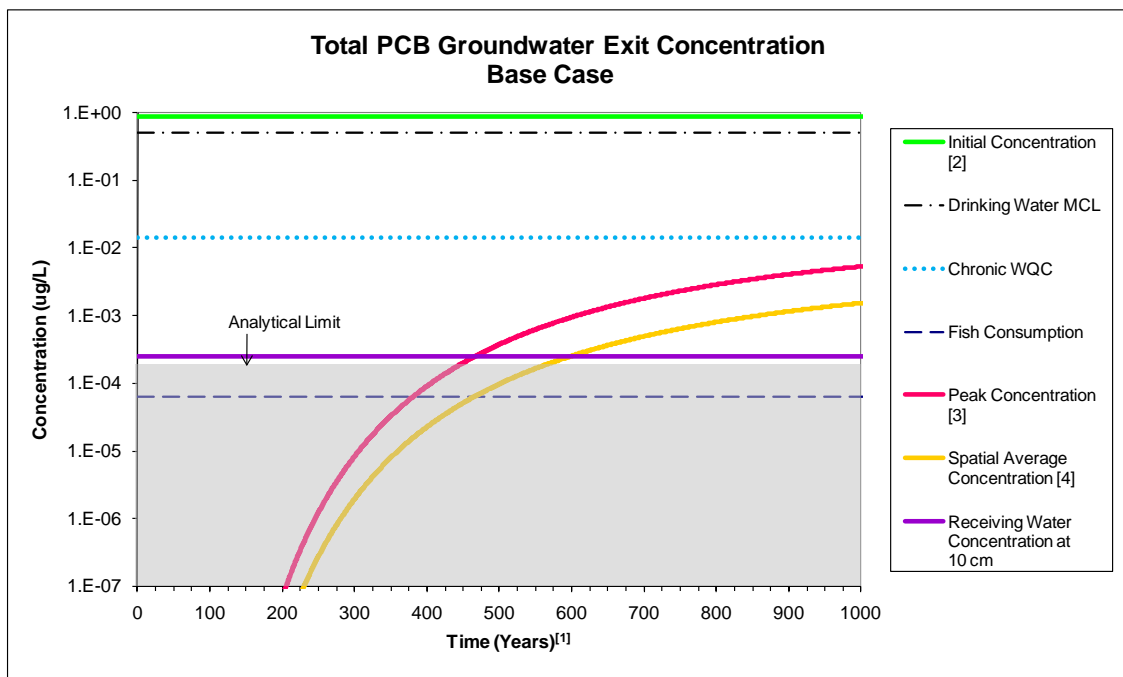


**Notes:**

Groundwater observation point is the predicted concentration in last model cell adjacent to river boundary, approximately one foot below the berm face.

- [1] Time zero refers to the time when CDF construction is complete. It may take up to 4 to 6 years to fill and cover the CDF.
- [2] Initial Concentration = sediment leachate concentration in CDF estimated using SBLT test results; see Appendix A and Table 6-7.
- [3] Peak Concentration = peak contaminant concentration in groundwater exiting the CDF berm.
- [4] Spatial Average Concentration = average contaminant concentration in groundwater exiting the CDF berm averaged vertically over the CDF berm face.

*This page left blank intentionally.*



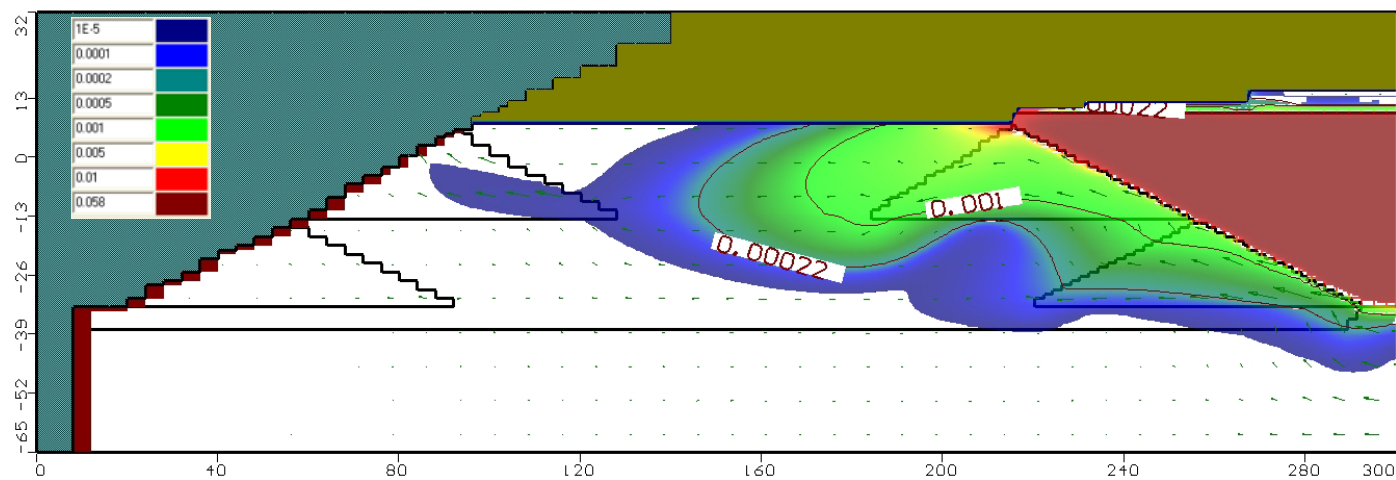
#### Notes:

Groundwater observation point is the predicted concentration in last model cell adjacent to river boundary, approximately one foot below the berm face.

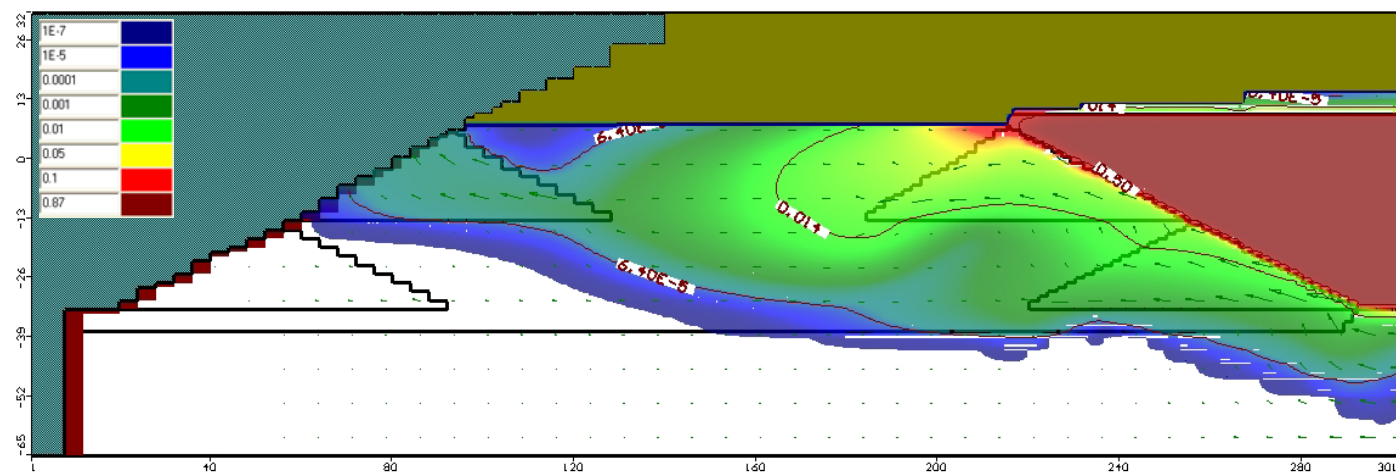
- [1] Time zero refers to the time when CDF construction is complete. It may take up to 4 to 6 years to fill and cover the CDF.
- [2] Initial Concentration = sediment leachate concentration in CDF estimated using SBLT test results; see Appendix A and Table 6-7.
- [3] Peak Concentration = peak contaminant concentration in groundwater exiting the CDF berm.
- [4] Spatial Average Concentration = average contaminant concentration in groundwater exiting the CDF berm averaged vertically over the CDF berm face.

*This page left blank intentionally.*





DDx at 475 years (in  $\mu\text{g/L}$ )



Total PCBs at 475 years (in  $\mu\text{g/L}$ )

*This page left blank intentionally.*